

ORIGINAL RESEARCH

THE RELIABILITY, MINIMAL DETECTABLE CHANGE AND CONSTRUCT VALIDITY OF A CLINICAL MEASUREMENT FOR QUANTIFYING POSTERIOR SHOULDER TIGHTNESS IN THE POST-OPERATIVE POPULATION

Paul A. Salamh, PT, DPT¹Morey J. Kolber, PT, PhD, OCS^{2,3}

ABSTRACT

Background: Posterior shoulder tightness (PST) has been implicated in the etiology of numerous shoulder disorders. Although reliable and valid measures have been described for the non-operative population one does not exist for the post-operative population.

Study Design: Blinded repeated measures design.

Purpose: Investigate the intrarater reliability, minimal detectable change at the 90% confidence interval (MDC_{90}) and construct validity of an inclinometric measurement designed to quantify PST in the post-operative population.

Methods: One investigator performed PST measurements on the operative shoulder of 23 participants. Passive internal and external rotation measurements were performed for the validity component of the investigation.

Results: Intrarater reliability using an intraclass correlation coefficient (ICC) model 3,k was good ($ICC = 0.79$). The MDC_{90} indicated that a change of greater than or equal to 8 degrees would be required to be 90% certain that a change in the measurement would not be the result of inter-trial variability or measurement error. Construct validity was supported by a statistically significant relationship between PST and internal rotation $r = 0.54$ and by a relationship between PST and external rotation $r = 0.30$ which was not statistically significant.

Conclusion: The sidelying procedure described in this investigation appears to be a reliable and valid means for quantifying PST in the post-operative population. Moreover, the use of inclinometry provides an absolute angle of tightness that may be used for intersubject comparison, documenting change, and to determine reference values.

Level of Evidence: Therapy, level 2b

Key Words: capsule, flexibility, mobility, range of motion

¹ Southeastern Orthopedics Physical Therapy, Raleigh, NC, USA

² Nova Southeastern University, Fort Lauderdale, FL, USA

³ Boca Raton Orthopaedic Group, Boca Raton, FL, USA

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CORRESPONDING AUTHOR

Paul A. Salamh

Director of Rehabilitation

Southeastern Orthopedics Physical Therapy

3404 Wake Forest Rd

Suite 201

Raleigh, North Carolina 27609

Phone: (919)-256-1524

Fax: (919)-256-1530

E-mail: psalamh@seortho.net

INTRODUCTION

Epidemiological data suggests that up to sixty-seven percent of the general population will experience shoulder pain at some point in their lifetime.¹ The shoulder complex ranks third among regions treated by physical therapists in outpatient clinics and has been reported to be a primary location of injury or pain among individuals who participate in weight-training, baseball, football and wrestling.²⁻⁶ A survey of American Shoulder and Elbow Surgeons Society members revealed that these surgeons performed on average greater than 300 shoulder cases annually.⁷ Although the etiology of shoulder disorders is multifactorial, specific impairments such as inadequate mobility and posterior shoulder tightness (PST) have been associated with common disorders such as labral tears and impingement syndrome in both the general and athletic population.⁸⁻¹³

Throwing athletes, in particular have a predilection for PST owing to repetitive microtrauma at the posterior capsule during the late cocking and follow through phases of the throwing motion.^{12,14} It has been postulated that tensile stresses placed on the shoulder during throwing may induce hypertrophy and thickening of the posteroinferior capsule thus producing PST.^{12,14} Although these capsular changes have been implicated in the etiology of PST, it must be recognized that muscular restrictions may be involved as well.¹⁵ Reinold et al¹⁶ found acute decreased internal rotation among professional baseball players following pitching that were present 24 hours following practice further supporting the contribution of acute musculotendinous adaptations on internal rotation.

Although common to the overhead athlete, PST has been reported among other subgroups of the population. Tyler et al⁸ reported increased PST among individuals diagnosed with impingement syndrome when compared to controls. Ticker et al¹⁷ reported an association between impingement syndrome and posterior capsular thickening-shortening among patients with a history of shoulder pain undergoing arthroscopy. Additionally, an association between PST and recreational weight-training participation has been reported among asymptomatic individuals when compared to controls suggesting the potential for task specific tissue adaptations.^{18,19}

Furthermore, shoulder stiffness has been reported as a post-operative complication among individuals having undergone shoulder surgery.²⁰⁻²² Brislin et al²⁰ reported persistent shoulder stiffness as being the most common complication following arthroscopic rotator cuff repair. A recent review of the literature regarding complications associated with arthroscopic rotator cuff repair reported the incidence of persistent post-operative stiffness to range from 1.5–11.1 % second only to the incidence of re-rupture.²² Huberty et al²¹ reported that 95.5% of patients with post-operative shoulder stiffness requiring a secondary capsular release had impaired internal rotation.

Clinical recognition of risk or pathology attributed to PST as well as changes as a result of specific treatments utilized to reduce PST requires a reliable and valid measurement technique that may be used among the heterogeneous population and that is of reasonable expense and availability. Measurement techniques for PST have been reported in the literature using both supine and sidelying procedures as well as with varying instruments including inclinometry, goniometry, and a tape measure.^{11,23-28} Essentially, the techniques described attempt to isolate glenohumeral horizontal adduction by restricting scapular movement.^{11,23-25,27} Tyler et al²⁵ first described a sidelying technique for quantifying PST, whereby the scapula is stabilized in retraction while the humerus is passively adducted across the chest, while being maintained at 90 degrees of forward flexion and neutral rotation. The distance from the medial epicondyle to the table is recorded with larger distances implying greater PST. Good intra and interrater reliability of this technique were reported, with an intraclass correlation coefficient (ICC) of 0.92 and 0.80 respectively.²⁵ Myers et al¹¹ assessed the intra and interrater reliability of the sidelying technique using a linear measurement device that recorded the distance between the table and medial epicondyle and reported ICCs = 0.42-0.83 and 0.69 respectively. A disadvantage of both of the aforementioned sidelying techniques is that PST is not quantified using an absolute value that can be directly compared between individuals. Other researchers have examined PST using supine measurements performed with either inclinometry or goniometry^{11,23,24} and reported good intra and interrater reliability (ICC = 0.75-0.94); however, a disadvantage of this technique is the inability to visualize a consistent start position of the scapula.

A modified sidelying measurement method, performed with the use of an inclinometer, to permit intersubject comparison has yielded good interrater reliability (ICC = 0.90).²⁸ A recent review of the literature in regards to methods for quantifying PST indicates that current research in this area has only been performed on the asymptomatic and or non-operative population, suggesting a need for investigation of quantifying PST in the post-operative population.²⁹ To our knowledge no previously published investigations have reported the intrarater reliability, minimal detectable change (MDC₉₀) and construct validity of a sidelying PST measurement using inclinometry within the post-operative shoulder population.

The purpose of this study was to investigate the intrarater reliability, MDC₉₀ and construct validity of a previously investigated sidelying inclinometric measurement technique designed to quantify PST²⁸ within the post-operative population. Construct validity was evaluated using passive internal rotation (IR) for convergence given the direct relationship between posterior capsuloligamentous tension and IR.³⁰⁻³² External rotation (ER) was used for discrimination as biomechanical studies have identified an absence of influence between PST and ER.³² The authors hypothesized that the PST measurement would have good intrarater reliability based on the nature of the testing procedures. In regards to validity, a strong positive relationship would exist between PST and IR with little or no relationship between PST and ER was hypothesized. Passive measurements of IR and ER were used to establish validity since participants had recently undergone shoulder surgery and the above-mentioned procedure for measuring PST is also performed passively.

METHODS

Participants

A convenience sample of 23 consecutive patients, 13 men and 10 women, seeking postoperative physical therapy following arthroscopic shoulder surgery between May 2011 and December 2011 were screened for eligibility in this study. The inclusion criteria consisted of patients having had arthroscopic shoulder surgery within the past two weeks preceding data collection with no surgical complications, age 18-65, and seeking treatment at Southeastern Orthopedic

Physical Therapy where the primary investigator of the study is employed. Exclusion criteria consisted of patients having had total shoulder arthroplasty, hemi shoulder arthroplasty, open rotator cuff repair, shoulder fracture fixations, and those seeking an initial evaluation after two weeks from the date of the surgical procedure. Demographic data was collected from each patient including gender, age, height, weight, and handedness. The mean \pm SD age, body mass index, and height for subjects was 51 ± 9.7 years, 26.67 ± 4.0 kg/m², and 173.60 ± 9.5 centimeters respectively and all 23 subjects were right hand dominant. Patients that met the inclusion criteria and agreed to be in the study were provided with and signed an informed consent form approved by the Institutional Review Board at Nova Southeastern University.

Instruments

A standard plinth and Baseline® bubble inclinometer (Fabrication Enterprises, White Plains, NY) was used for each of the measurements performed in this study. The measurements of PST were performed using a bubble inclinometer attached to a Velcro strap that was placed around the patients mid-humerus (Figure 1). A 24-inch bubble level (Johnson Level & Tool, Mequon, WI) was used to set the inclinometer to a zero point in regards to the starting position (such that the zero point was perpendicular to the plinth) before measurements were taken and after any handling of the inclinometer to ensure an accurate zero starting point.



Figure 1. Baseline® Bubble Inclinometer attached to Velcro strap.

Procedures

Prior to all measurement procedures patients performed a standard warm up that was not believed to offer a mobilization effect or affect PST. The purpose of the warm up exercises was to reduce potential soreness from the measurement positions without effecting PST. Warm up exercises consisted of 10 scapular retractions in a seated position and 10 pendulum exercises, performed with approximately 45 degrees of trunk flexion and no weight, in small clockwise circles. Following the warm-up exercises, PST was measured in the operative shoulder and repeated three times with a 10 second rest between each measurement. The patient was allowed to rest for 10 minutes. Warm-up exercises were again performed after the 10 minutes of rest and then three repeated PST measurements were again taken. This short test/re-test interval was specifically chosen given the rapid rate at which post-operative shoulder range of motion changes. Moreover, given the risk of arthrofibrosis patients are routinely treated on day one therefore measurements performed on a different day would have been invariably higher, thus compromising agreement. After the second set of PST measurements was performed, passive IR and passive ER of the operative shoulder were also measured using an inclinometer. Prior to testing, uniform verbal instruction was provided to each patient regarding the positioning of their arm and to promote relaxation. A physical therapist trained in recording data from the inclinometer recorded all measurements on single data collection sheet to ensure that the clinician was blinded to the findings. A single clinician with over four years of experience in an orthopedic shoulder setting performed all measurements.

Posterior Shoulder Tightness Measurement

The procedure for measuring PST was adapted from the protocol used by Kolber and Hanney.²⁸ The inclinometer was placed around the mid-humerus of the operative arm using a Velcro strap. The patient was asked to lie on their non-operative side with their non-operative arm under their head to assume neutral head position. Their trunk was perpendicular to the plinth and both the hips and knees flexed to 45 degrees. A carpenter's square was not used to ensure the trunk remained perpendicular to the plinth because the authors wanted to accurately simulate

how this measurement would be applied in clinical practice. A bubble level was used to establish a zero starting position (such that the zero point was perpendicular to the plinth) for the inclinometer in regards to horizontal adduction. The clinician stood facing the patient at the level of their shoulders. With one hand the clinician grasped the elbow of the operative arm and passively abducted the humerus to 90 degrees while maintaining zero degrees of rotation at the humerus and approximately 90 degrees of elbow flexion. The hand used to grasp the patients elbow maintained its position while the clinicians other hand was used to grasp the patient's scapula and position it into full adduction (retraction). This established the starting position for the measurement with the humerus abducted to 90 degrees, zero degrees of humeral rotation, approximately 90 degrees of elbow flexion, and full scapular retraction (Figure 2A). At this time the clinician provided verbal commands to the patient similar to "relax your arm as I move it towards the table" before passively moving the humerus into horizontal adduction within the transverse plane while maintaining retraction of the scapula and zero degrees of humeral rotation. The clinician ceased the movement when he felt that the humerus or scapula could no longer be stabilized or when movement stopped (Figure 2B). At this time the trained assistant recorded the measurement from the inclinometer.

Passive Internal Rotation Measurement (IR-PROM)

The procedure for measuring IR-PROM was performed with the patient in supine and the patients operative arm entirely supported by the plinth. The patients humerus was passively abducted to 90 degrees while in zero degrees of rotation, the elbow flexed to approximately 90 degrees and the wrist in neutral. Neutral horizontal positioning of the humerus was achieved in this position by placing folded towels under the operative arm until the humerus was visually in line with the acromion process. The clinician placed one hand on the operative anterior shoulder to prevent protraction of the shoulder and with the other hand grasped the posterior wrist/hand of the patient's operative extremity. The humerus was internally rotated while in the above position until the movement ceased or the clinician felt anterior

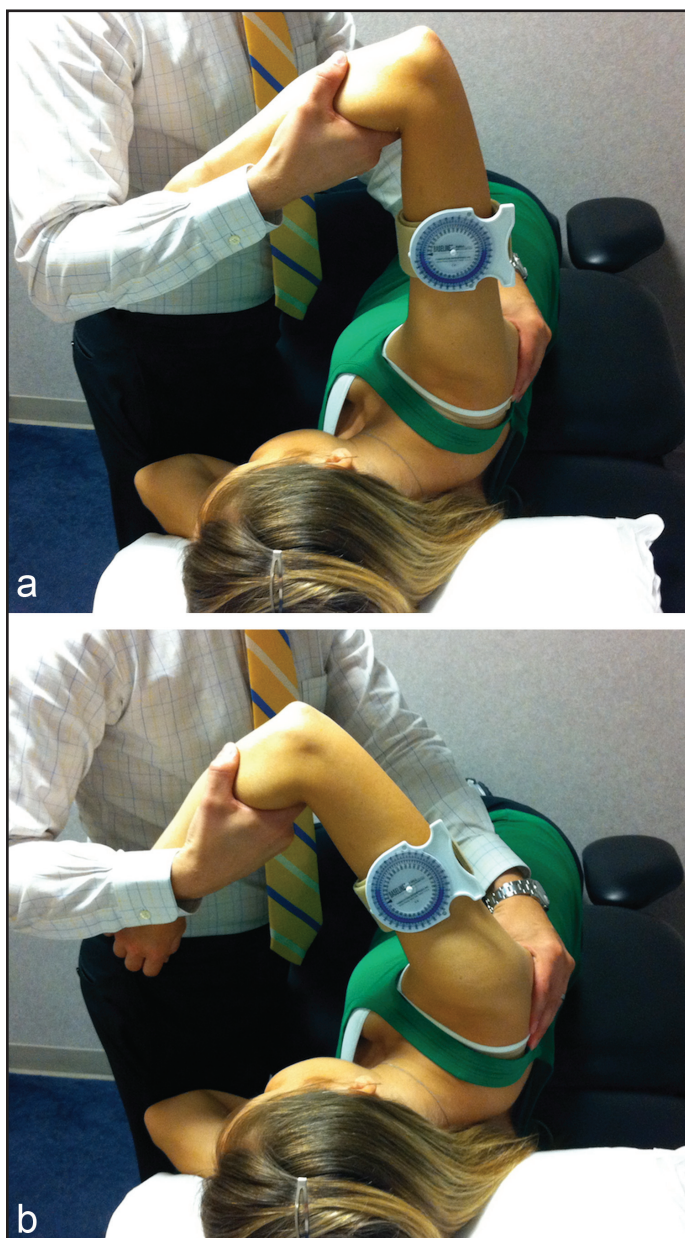


Figure 2. Sidelying posterior shoulder tightness measurement technique using an inclinometer (a) Start position for posterior shoulder tightness measurement with participant's arm passively positioned in 90° abduction by examiner and scapula retracted as illustrated (b) Examiner passively lowers arm across chest into horizontal adduction while manually retracting the scapula through contact with the lateral border. The angular measurement is recorded from the inclinometer.

pressure against his stabilizing hand (Figure 3). At this time the trained assistant placed the inclinometer along the distal anterior forearm and recorded the measurement. The supine method for measuring internal rotation was selected over the prone method secondary to increased pain the patient may have



Figure 3. Passive range of motion measurement for internal rotation. Participant is supine with arm supported on the table in 90 degrees of abduction and forearm flexed to 90 degrees. A towel roll is placed directly under the arm to provide stabilization and maintain the arm in a neutral position with regard to the transverse plane. Participants arm is passively brought into internal rotation as illustrated above. Examiner places inclinometer on the distal forearm just proximal to the wrist once participant reaches passive end-range with one hand while the opposite hand is placed on the anterior shoulder to prevent protraction of the shoulder.

experienced by lying on the operative shoulder and may have potentially prevented an accurate measure of internal rotation from being obtained.

Passive External Rotation Measurement (ER-PROM)

The procedure for measuring ER-PROM was performed with the patient in supine with their operative arm entirely supported by the plinth. The patient's humerus was passively abducted to 90 degrees while in zero degrees of rotation, the elbow flexed to approximately 90 degrees and the wrist in neutral. Neutral horizontal positioning of the humerus was achieved in this position by placing folded towels under the operative arm until the humerus was visually in line with the acromion process. The clinician placed one hand on the operative shoulder to stabilize the shoulder complex and with the other hand grasped the posterior wrist/hand of the patient's operative extremity. The humerus was externally rotated while in the above position until the movement ceased (Figure 4). At this time the trained

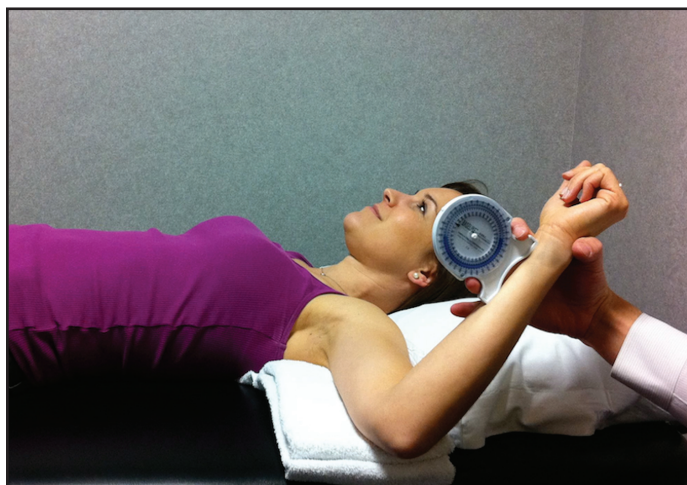


Figure 4. Passive range of motion measurement for external rotation. Tested arm is supported on the table in 90 degrees of abduction, elbow flexed to 90 degrees. A towel roll is placed under the humerus. Participants arm is passively brought back into external rotation. Once passive end-range is achieved the examiner places inclinometer on the distal forearm just proximal to the wrist.

assistant placed the inclinometer along the distal anterior forearm and recorded the measurement.

Data Analysis

Collected data was transferred to the Macintosh version of PASWStatistics Version 18.0 for analysis. Descriptive data including mean measurement angles with standard deviations (SD) were calculated for each series of measurements. The intrasession reliability of PST was determined by the ICC model 3, *k*. The mean value of each series of measurements was used for the analysis. Model 3, *k* was used for the intrarater analysis to determine if this particular instrument can be used repeatedly with confidence by the same clinician.^{33,34} Our interpretation of the ICC value was based on guidelines offered by Portney and Watkins³³, whereby a value of above 0.75

was classified as good and a value of 0.50 to 0.75 would be considered to have moderate to poor reliability. The standard error of measurement (SEM) is not affected by intersubject variability³⁵ and is important for clinical utilization of a measurement procedure; therefore it was reported in conjunction with the ICC's using the formula: $SEM = SD \sqrt{1-r}$.³³ The MDC was calculated for the intrarater measurements using the formula: $MDC_{90} = 1.65 * SEM * \sqrt{2}$ to determine the magnitude of change that would exceed the threshold of measurement error at the 90% confidence level.^{33,36} MDC_{90} values were rounded to the nearest degree to reflect the smallest unit of measurement on the inclinometer.

Pearson product-moment coefficient of correlation (*r*) using a significance level of $p = 0.01$ was used for the analysis for the construct validity component of the investigation. This was used to determine if a relationship existed between PST and IR as well as PST and ER. An *a priori* power analysis indicated that a sample size of 22 would be needed to obtain 80% power when using an estimated $r = 0.50$ with the $\alpha = 0.05$.

RESULTS

Mean angular measurements of PST for the intrarater reliability analysis with SD, ICC (95%CI), SEM, and MDC_{90} are presented in Table 1. The data indicates good intrarater reliability for PST (ICC = 0.79). The MDC_{90} for the intrarater analysis indicated that a change equal to or greater than 8° would be required to be 90% certain that the change is not due to intra-trial variability or measurement error.

Convergent validity was supported by a statistically significant moderate correlation between PST and internal rotation ($r = 0.54$) with $p = .008$. Discriminant validity was supported given there was no

Table 1. Intrarater Reliability Analysis: Posterior Shoulder Tightness Measurement.

Shoulder Test	Measurement A Mean angle°(SD)	Measurement B Mean angle°(SD)	ICC 3,k (95% CI)	SEM°	MDC° ₉₀
PST	22.04(7.51)	23.93(9.35)	0.79(0.51-0.91)	3	8
Abbreviations: SD, standard deviation; ICC, intraclass correlation coefficient; CI, confidence interval; SEM, standard error of measurement; MDC_{90} , Minimum detectable change at the 90% confidence level; PST, posterior shoulder tightness.					

Table 2. Measurement Angles used for Construct Validity Analysis.				
Shoulder Test	Mean angle°(SD)	Range°	Minimum°	Maximum°
PST	23.93(9.35)	37	8	45
Internal Rotation	21.65(12.28)	56	4	60
External Rotation	48.73(13.05)	43	60	68
<i>Abbreviations: SD, standard deviation; PST, posterior shoulder tightness</i>				

statistically significant correlation between the PST measurement and external rotation ($r = 0.30$) with $p = .166$ indicating little or no relationship. Table 2 presents the PST, IR and ER measurements (mean, SD and ranges) that were obtained.

DISCUSSION

This investigation sought to determine the intrarater reliability, MDC, and construct validity of a measurement procedure designed to quantify PST within the post-operative population. Although the posterior capsule and ligamentous structures have been implicated as primary contributors to PST^{17,30,32} it can not be stated with absolute certainty that they are the only source of PST, therefore, clinicians must appreciate the potential contribution of contractile tissue.¹⁵ The term PST collectively encompasses the posterior capsule, posteroinferior glenohumeral ligament as well as the tendinous portion of the posterior rotator cuff and posterior deltoid musculature.^{15,17,30,32,37} Evidence for contractile tissue contribution may be gathered from the study by Hung et al¹⁵, where it was reported that muscle stiffness (change in passive tension per unit change in length) increased in the posterior deltoids, teres minor, and infraspinatus when internally rotating the shoulder of patients with limited mobility, whereas muscle stiffness was reduced during external rotation. PST within the post-operative population may also be attributed to inflammation and or pre-operative tightness in the above-mentioned tissues.

Regardless of the soft tissues involved, a reliable and valid measurement technique is necessary for clinicians and researchers to recognize and quantify PST in the post-operative population. Clinical measurements isolating PST have been described in the literature;^{11,23-25,27} however, there is no consensus as to the best method.²⁹ A procedure that allows the

examiner to consistently maintain scapular positioning independent of body morphology while providing an absolute measurement value would be a clinically useful test.

The inclinometric measurement procedure described and examined in this investigation provided optimal positioning for identifying PST and was developed based on in vivo and in vitro investigations of tissue tension.³⁰⁻³² Moreover, the investigated procedure provides an absolute value that may be used to document change, be useful for intersubject comparison, and can be performed by a single clinician without assistance.

Although the sidelying measurement procedure has been previously described, this investigation is the first to report the intrarater reliability, and MDC₉₀ values of this method using inclinometry within the post-operative shoulder population. Previous researchers have described alternate procedures for quantifying PST in a non-operative population with fair to good reliability; however, there is disagreement on what constitutes the optimal position and measurement instrument for assessment.²⁹ There is, however, a consensus that an optimal technique for quantifying PST requires isolation of true glenohumeral horizontal adduction independent of scapular protraction. Thus, optimal techniques should allow the examiner to maintain scapular retraction throughout the measurement and provide an accurate start position of retraction. Laudner et al²³ used a supine method for quantifying PST and reported good intrarater and interrater reliability, ICC = 0.93 and 0.91 respectively using digital inclinometry in asymptomatic participants. While the reliability values were good and the authors describe a clear reproducible methodology the supine position used may not permit a consistent start position of the scapula

for all participants given varied body morphology. If the scapula is not in full retraction the testers might underestimate PST. Moreover, the aforementioned study was performed on an asymptomatic population and the results cannot be carried over into a symptomatic cohort. Using the SEM value reported from the aforementioned study an MDC_{90} of 4 degrees was calculated. Lastly, digital inclinometry is costly, thus clinicians may not have this instrument at their disposal for routine use.

The sidelying method for quantifying PST has previously been investigated by Tyler et al²⁵ with good inter-rater reliability, ICC = 0.80. Advantages of the sidelying technique include a reproducible method of scapular stabilization, which isolates PST and provides a consistent, objectifiable start position. A measurement of the distance between the medial epicondyle and the plinth is thought to quantify PST; however, a disadvantage of this measurement method is that it does not produce a value that could be used for comparison between individuals or to establish normative values due to the varying anthropometric characteristics between individuals. The procedures described in this paper are similar to the methods originally described by Tyler et al²⁵ with the exception that an inclinometer was used in this investigation for angle measurements as compared to linear measurements. Inclinometry allowed the authors of the current study to obtain an absolute value for the angle of the humerus, which can be used for intersubject comparison. The intrarater reliability of the sidelying procedure described in the aforementioned investigation was good (ICC = 0.79) but as is the case with all the aforementioned investigations, it cannot be generalized to the post-operative population. The authors of the current investigation chose to not measure PST in supine, as it is difficult to identify a consistent start position of the scapula. Moreover, the authors found it difficult to maintain a fully retracted scapular position during the measurement.

While reproducibility is imperative for any measurement, validity must be established in order to be certain that a measurement provides accurate information for clinical decision-making.³³ Construct validity may be evaluated by determining how well a measurement relates to other tests of the same and different constructs. PST and IR are thought to measure the same construct,^{30,32} therefore these measurements

would be expected to correlate highly or demonstrate convergence. Convergence alone is not a sufficient criterion to determine construct validity. It is also necessary to show that a construct may be differentiated from another construct, thus demonstrating the ability to be discriminant.³³ Discriminant validity indicates that different results or poor correlations would be expected from measurements that assess a different construct or characteristic.³³ ER should not be markedly affected by tension in the posterior capsuloligamentous or contractile tissues, thus a positive correlation would not be expected when compared to measurements of PST.^{15,32}

Conflicting evidence in regards to the validation of PST measures stated above can be seen in the recent study by Borstad and Dashottar³⁸ which attempted to quantify strain on posterior shoulder tissues using 5 cadaveric shoulders (fresh and fresh-frozen). The authors claim that the literature to date does not establish construct validity for current PST measurements. This study examined the strain on the posterior glenohumeral joint capsule with different testing positions, one being horizontal adduction. The positions that produced the greatest strain on the posterior glenohumeral joint capsule were the 60 degrees flexion and 40 degrees flexion positions, with the cross-body abduction test position not strongly affected by changes in posterior capsule contracture. There are however limitations to any cadaveric study in regards to the applicability of the results in a clinical setting. One of the largest limitations of the Borstad and Dashottar³⁸ study is in regards to the portion of the capsule that was thermally altered to best mimic a posterior capsule contracture being very broad, when the portion of the capsule most commonly involved in pitchers as well as clinically observed in degenerative shoulder cases (by the primary author) is the inferior glenohumeral ligament.³⁹ The authors also did not position the scapula in retraction during testing which is different than the horizontal adduction methods used to measure PST in the literature.^{25,28,40-43} Moreover, the mean age of the shoulders examined was 80.9 years which is considerably older than the average age (43.5) for which patients present to outpatient clinics.³

The choice of shoulder motions for the validity component of the current investigation was based on

both in vitro and in vivo evidence from the literature. IR was utilized for assessment of construct validity as osteokinematic impairments of IR at the glenohumeral joint have been associated with PST.^{8,12,14,15,24,25,30,31} Gerber et al³⁰ performed surgical shortening of the posterior capsule and reported a significant reduction in internal rotation as a result confirming the association between posterior capsular tension and IR. Harryman et al³¹ noted a loss of shoulder flexion, horizontal adduction, and internal rotation following in vitro tightening of the posterior capsule, similar to the results of Gerber et al³⁰ and Tyler et al^{8,9} identified an association between PST and internal rotation loss using clinical measurements among subjects with impingement syndrome. Branch et al³² investigated the effect of capsular tension on shoulder rotation in vitro. The study results from Branch et al³² suggest a direct relationship between IR and tension in the posterior capsuloligamentous tissues, whereas a similar relationship was not found with ER.

The results of the current study's validity analysis suggest a statistically significant relationship between PST and IR. The mean angle of IR and PST rounded to the nearest degree was 22° and 24° respectively with a statistically significant moderate correlation ($p = .01$) $r = 0.54$. Conversely, there was no correlation between ER and PST ($r = 0.30$). These results are consistent with previous studies that documented a positive association between PST and decreased internal rotation.^{8,10,11,15,17,24,25,28,30,32,37} Tyler et al²⁵ reported a good correlation between PST and IR using the sidelying PST measurement method among baseball pitchers and reported $r = -0.61$. An inverse correlation was reported based upon their use of a linear measurement whereas a loss of internal rotation correlated with a greater distance measured from the medial epicondyle to the plinth. Laudner et al²³ reported a good correlation between IR and PST ($r = 0.72$) among baseball pitchers. Lin and Yang²⁴ compared PST to both IR and ER in a symptomatic cohort and reported a good relationship for IR ($r = 0.69$), whereas ER had little or no relationship ($r = 0.25$). Hung et al¹⁵ measured muscle stiffness using a myotonometer, in response to IR and ER among participants with clinically reduced ROM and identified increased stiffness (change in passive tension per unit change in length) of the posterior musculature in response to IR lending

support to the possible contribution of contractile tissue to PST.

Kolber and Hanney²⁸ were the first to report MDC scores for measurements used to quantify PST with a value of $MDC_{90} = 9$ degrees within an asymptomatic population. The MDC_{90} values reported in this investigation indicate that a change greater than or equal to 8° is required over treatment sessions or in research trials to be 90% certain that the change is not due to subject variability or measurement error. This MDC value may be a reflection of the population chosen for this investigation. Patients having recently undergone shoulder surgery may experience increased pain, muscle guarding, and a general fear of shoulder mobility during passive shoulder motion. Subsequent measurements may lessen these effects and allow for a greater range of motion. The MDC as reported in this investigation is the smallest amount of change that can be considered above the threshold of error,³³ however, one must not make the assumption that this change has reached the threshold of clinically meaningful improvement. When interpreting change scores it should be recognized that the MDC is not the same as the minimum clinically important difference (MCID).³³ The MCID is the amount of change that is clinically meaningful and is typically associated with an external criterion that indicates when meaningful change has occurred.³³ The MCID was not calculated in this investigation, thus it is uncertain as to the degree of change that would be considered clinically meaningful.

Limitations

When considering the results of this study one must recognize potential limitations. This study used only post-operative participants, thus the results may not correlate with a non-operative cohort. Our age range was 32 to 64, thus future investigations are warranted on populations of a different age range if the results are to be generalized to the population. This study only investigated intrarater reliability and requires further research to investigate interrater reliability of this particular method. Lastly, one must be cautious in their interpretation of the MDC values reported in this investigation, as they are not indicative of clinically meaningful change. Future research is warranted to further investigate PST

within the post-operative population to study open shoulder procedures, compare different techniques used to quantifying PST, determine interrater reliability of certain techniques, and continue to investigate the construct validity among proposed measures of PST.

CONCLUSION

Various procedures and instruments have been described in the literature for quantifying PST, thus it is difficult to state that the method described and investigated in this paper is superior to others and may be a potential limitation to this study. This investigation presents a reproducible and valid measurement protocol for quantifying PST in the post-operative population using an inclinometer. The clinical utility of such a procedure is high, due to low cost examination tools. The inclinometric procedure outlined in this investigation had a reliability coefficient of 0.79 which is the threshold recommended for tests to be useful in making clinical decisions³³ and is a suitable alternative to linear measurements as it allows for intersubject comparison. Clinicians and researchers should consider the MDC values presented (8°) when interpreting change values during subsequent measurement sessions to be certain that the change is not due to intertrial variability or measurement error.

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